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IDENTIFICATION OF SARAS FLIGHT STABILITY AND CONTROL CHARACTERISTICS

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Abstract : *Longitudinal stability and control characteristics and the neutral point of Saras aircraft are estimated from flight test data by applying classical and parameter identification techniques. The accuracy of the nose boom and the side-mounted angle-of-attack vanes is assessed using steady-state level flight data. The angle-of-attack accuracy is also assessed by applying flight path reconstruction techniques to flight data from short period pitch stick maneuvers. Results from the classical and parameter identification techniques are compared with the design data from wind tunnel tests.*

1. INTRODUCTION

Saras is short haul light transport aircraft being designed and developed by NAL. Major roles envisaged for Saras include commuter, executive travel, air-ambulance and surveillance. The pre-flight aero database, referred to as design data, for this aircraft is generated mainly from wind tunnel tests and by using analytical tools. Verification and validation of this aero database from flight test data becomes necessary because of inherent errors associated with these basic design tools. For this purpose, the aircraft is instrumented with various onboard sensors to measure aircraft responses to pilot inputs. Initial calibration and assessment of each measuring instrument is carried out to ascertain the data output quality. Both classical method and parameter estimation techniques are used for carrying out post flight data analysis. This paper presents some typical results of longitudinal data analysis, neutral point estimation and angle-of-attack sensor calibration. The results are compared with the design data from wind tunnel tests.

2. ANALYSIS USING CLASSICAL METHOD

A preliminary assessment of the aircraft static longitudinal stability and neutral point is made based on classical techniques wherein the steady state response from SARAS PT-1 aircraft is used to extract its longitudinal characteristics. First, the flight test data were generated to determine the elevator deflections required to hold a particular aircraft speed during descents at low engine torque. Though the engine torque was low, suitable corrections were applied to bring these data to power-off state. Engine and propeller data provided by the respective manufacturers are applicable for only un-installed conditions and therefore, do not have enough information to ascertain the engine torque leading to zero thrust under installed conditions. For flaps zero configuration, the data of engine torque needed to realize zero thrust condition were generated from flight tests[1]. Fig. 1 shows how the engine torque for zero thrust varies with aircraft speed. Using this information, flight data were interpolated for torque values corresponding to zero thrust for the speeds considered. A typical case of 130 kcas is illustrated in Table 1. Fig. 2 shows the variation of elevator with lift coefficient in power-off state, for flap zero configuration.

It is well known that the parameter dC_m/dC_L represents the static longitudinal stability of an aircraft flying in steady state. In the present investigations, dC_m/dC_L is computed by obtaining ($d\delta e/dC_L$) from flight test results and the elevator power ($dC_m/d\delta e$) from other reliable sources like wind tunnel tests. The ($d\delta e/dCL$) values are obtained for a range of speed from 110 kcas to 140 kcas with a single location of center of gravity. The dC_m/dC_L values are computed with high confidence since the elevator power obtained from flight tests and wind tunnel results was observed to be very nearly the same[2]. With the aircraft static longitudinal stability and the C.G location known, the neutral point of the aircraft is computed and compared with the design data in Table 2.

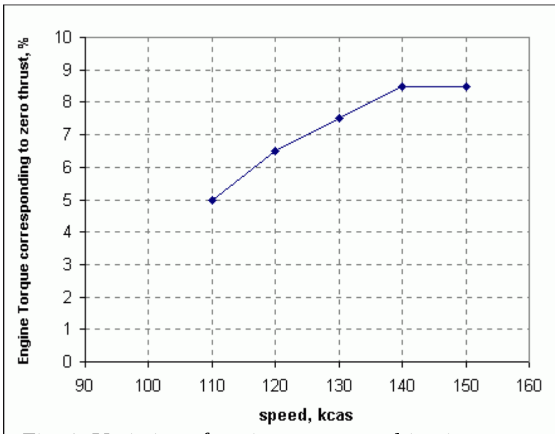

Fig. 1 Variation of engine torque resulting in zero thrust with aircraft speed [1].

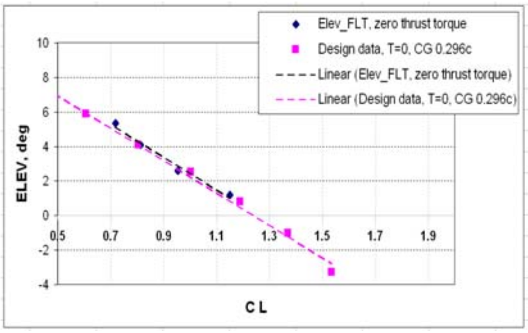

Fig. 2 Comparison of design data with flight data converted to power-off (flap zero)

Table 1 Computing elevator deflection for power-off condition

Flight #	Speed (kcas)	Engine torque (each engine)	Elevator (deg)
36	130	5%	4.5
39	130	10%	4.0
	130	9% (Torque for zero thrust from [1])	4.5+(9-5)*(4.0-4.5)/(10-5)=4.1 Elevator required in power-off condition=4.1 deg

Table 2 : Neutral point location by using classical method

Data source	Configuration	Neutral Point (N_o)	Remarks
Flight	Flaps zero	50%	Brought to power-off
Design	Flaps zero	49.5%	Power-off
Flight	Flaps zero	51%	Power-on ; level flight

3. ANALYSIS USING PARAMETER ESTIMATION TECHNIQUES

Longitudinal aerodynamic derivatives of Saras aircraft are derived from the flight test data using parameter identification (PID) techniques. A general approach to flight data analysis is shown in Fig.3 in the form of a block diagram. In this approach, the aircraft responses to control inputs are used to identify the aerodynamic derivatives in a mathematical model that result in the best representation of the aircraft measured flight data[3]. Various steps in the procedure include data acquisition, data preprocessing, model structure determination, parameter estimation and model validation. The flight-identified aerodynamic characteristics are compared with those predicted by wind tunnel tests.

There are several methods for the estimation of aircraft parameters from flight test data[4]. Their basic differences are due to assumptions made for optimal criterion, which reflects the existence of external disturbances and presence of noise in the data measured. The most widely accepted method of parameter estimation is the output error method. It also provides the standard deviations (Cramer-Rao bounds) of the estimated values of the derivatives that can be used as a measure of reliability of the estimates.

3.1 Flight test data

Acquisition of flight data is a major exercise in application of PID techniques. This primarily addresses the issue of obtaining time history measurements of the input and output variables. The input variables are control surface deflections and output variables are the air data signals (speed, angle of attack and sideslip), aircraft attitude (Euler) angles, angular rates and linear accelerations. In addition to these variables, the quantities defining flight conditions (Mach number and Altitude), flight configuration, fuel consumption, mass, C.G and inertia characteristics are also required. For successful parameter estimation, a fair knowledge of sensor characteristics (bias and position errors), data recording method, data filtering, digitization process like sampling rate and resolution, time tagging, etc. is required.

In order to identify the longitudinal derivatives of the Saras aircraft, flight data were gathered from elevator inputs at an altitude of 9000 feet and speeds of 120 kts and 135 kts. The aircraft was tested for clean configuration with undercarriage in retracted position. To estimate the neutral point, the aircraft was flight-tested to gather data from elevator inputs for three C.G positions (aft, mid and forward).

3.2 Data compatibility check

Since the measurements are always subject to systematic and random errors, it is essential to verify the accuracy of data by a compatibility check. It is also referred to as kinematic consistency check or the flight path reconstruction[4]. The flight test data from Saras aircraft were subjected to compatibility checks and errors in the form of time lags, bias and scale factors were estimated. Measured rates and accelerations were found to be clean with minimal bias errors. However, significant time lags and bias errors were observed in air data measurements. The measured flight data were appropriately corrected for there errors before using them for parameter estimation.

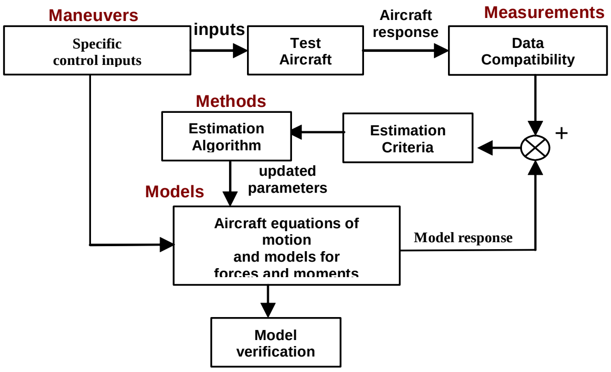

Fig. 3 Schematic block diagram of aircraft parameter estimation

3.3 Estimation Results

Longitudinal stability and control derivatives and the aircraft neutral point were estimated from Saras flight test data by applying output error parameter estimation method. Data from short period maneuvers were analyzed to determine the lift force and pitching moment derivatives. Figure 4 compares the flight-estimated values of C_{m_α}, C_{m_q} and $C_{m_{\delta_e}}$ with the values obtained from wind tunnel database. The estimates were found to be in good agreement with wind tunnel values. To estimate the aircraft neutral point, the state space model was formulated in a dimensional form and the unknown pitching moment derivatives were estimated from the elevator input flight data gathered for three different C.G positions. Fig.5 shows the plot of estimated M_α with C.G position. The straight line that passes through all these points intersects the x-axis at a point where M_α is zero. This defines the neutral point of the aircraft. The estimated value of neutral point from this approach is 49.9%, which compares well with the value provided by the classical method and the design data in Table 2.

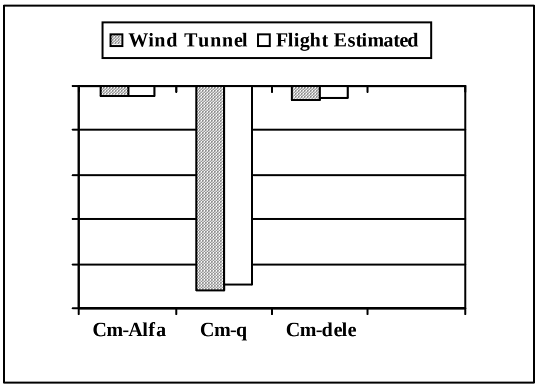

Fig. 4 Estimates of pitching moment derivatives of SARAS

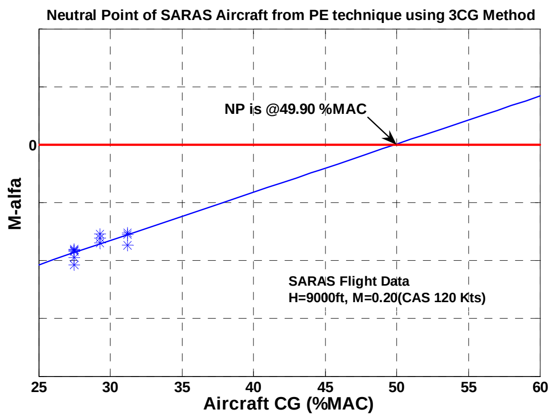

Fig 5 Estimation of Neutral point using PID techniques

Along with the assessment of longitudinal stability, the accuracy of the angle-of-attack (AOA) sensors mounted on the aircraft was also determined. An AOA vane is mounted on the nose boom while, two AOA vanes, one on each side are mounted on the fuselage. Fig. 6 shows the comparison of the wind tunnel AOA, nose boom AOA and the side-mounted AOA vane measurements, in terms of $CL_{POWER\ OFF}$ vs AOA for zero flap deflection[5]. It can be observed that the nose-boom vane indicates a higher AOA, for a given lift coefficient, than that shown by the WT data. On the other hand, the side-mounted AOA is reasonably close to wind tunnel AOA. Data available for pitch attitude angle showed reasonably good match with the side-mounted AOA measurements. These results were also confirmed through kinematic consistency check (KCC) carried out using flight path reconstruction techniques. The reconstructed nose boom AOA and the side-mounted AOA are plotted against the true AOA in Fig. 7 for zero flap condition. A difference of nearly 2.5 to 3 deg is observed between the nose boom and the side-mounted AOA, which correlates well with the results shown in Fig. 6.

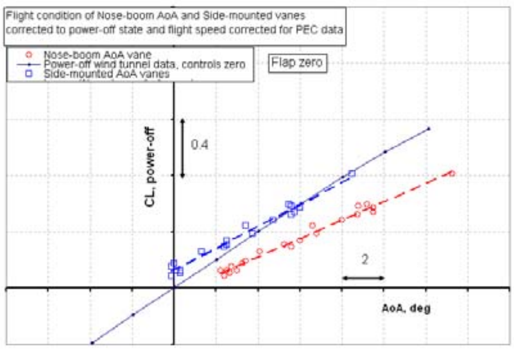

Fig 6 AOA measured in-flight vs. wind tunnel data (Flaps zero)

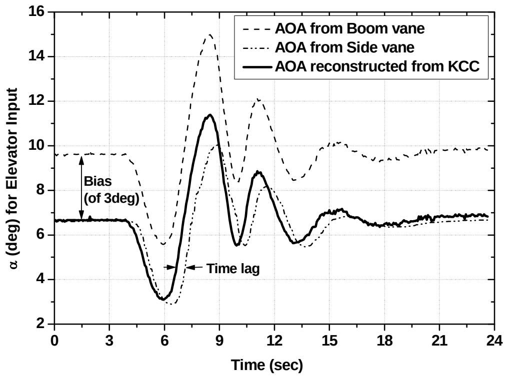

Fig 7 Nose boom, side-mounted and true AOA obtained using flight path reconstruction technique (Flap zero)

4. CONCLUSIONS

The longitudinal stability and neutral point of Saras aircraft are estimated from flight data using the classical methods and the more advanced PID techniques, and the results are found to compare well with each other and with the design data from wind tunnel tests. An assessment of the accuracy of the angle-of-attack sensors shows the nose boom vane angle-of-attack to be higher than the design data from wind tunnel tests.

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